EVALUATION OF STRENGTH CHARACTERISTICS OF STEEL SLAG HYDRATED MATRIX

A THESIS SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Civil Engineering

By

MEENA MURMU

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008

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Under the Guidance of

Prof. Mrs. Asha Patel
Prof. S.P. Singh

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NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA – 769008, ORISSA
INDIA

CERTIFICATE

This is to certify that the thesis entitled, **“EVALUTION OF STRENGTH CHARACTERISTICS OF STEEL SLAG HYDRATED MATRIX”** submitted by **Meena Murmu** in partial fulfillment of the requirements for the award of **Master of Technology** Degree in **Civil Engineering** with specialization in **Structural Engineering** at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Prof. S.P. Singh

Dept of Civil Engineering

National Institute of Technology

Rourkela – 769008

Prof. Asha Patel

Dept of Civil Engineering

National Institute of Technology

Rourkela – 769008

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Meena Murmu
ROLL NO-207CE212
NIT ROURKELA

Place-ROURKELA
Date-26.5.2009

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ABSTRACT

Use of more and more environment-friendly materials in any industry in general and construction industry in particular, is of paramount importance. Environment of this ‘only living’ planet is wary of pollution due to emissions of a host of green house gases from industrial processes. Present day construction industry consumes huge amount of concrete and cement is the binding material used for making concrete. During production of cement huge amount of energy is needed and about 8 % of CO_2 is released to atmosphere during cement production. This makes concrete a non eco-friendly material. In consideration of these points, construction industry has devised a substitute for concrete, popularly known as ‘Steel Slag Hydrated Matrix’. It consist of steel making slag, ground granulated blast furnace slag, fly ash, lime and water. The striking feature of this form of concrete is that most of its important ingredients are 100 percent by-products of industries, yet having similar performance record as any other conventional concrete material. Aesthetically also it has good pleasing colour and performance wise it has an excellent resistance to wear and tear. Burning of fossils fuels exclusively for its primary ingredients is not necessary unlike in the cue of cement and also no energy-intensive for cement clinker production. It also utilizes the waste products of industries like fly ash and steel slag which otherwise would pose problem for their safe disposal and sometimes degrades the environment.

In the present study tests are carried out in two phases. In the first phase of tests, the quantity optimization of raw materials like fly ash and hydraulic lime is made so as to get a best binding material that resembles the conventional binder, the cement. The conventional procedure followed to characterize the quality cement is adopted in this phase of tests and best raw material composition was arrived at. The lime content in the lime-fly ash mix was varied as 20, 35, 50,

65, 80 and 100%. Mortar cubes were made with lime- fly ash mix (as mentioned above) and Ground granulated blast furnace slag as fine aggregate in the proportions of 1:2 and 1:3. The compressive strengths of these cubes were determined after 3days, 7days 28 days and 60days of curing period. From the above series of tests the optimum mix was found out. In the second phase of tests, concrete specimens were prepared with taking steel slag as coarse aggregate, ground granulated blast furnace slag as fine aggregate and binder that is found to best performance from the test of phase one. Two compositions of above raw materials were taken that is 1:1.5:3 and 1:2:4 and the compressive strength, flexural strength and tensile strength were determined adopting conventional testing procedure. To find out the effect of curing period on the compressive strength, flexural tensile strength and split tensile strength the samples were cured for 7 days and 28 days and tested.

From the present study following conclusion were drawn:

Initial setting time, final setting time and consistency of fly ash and lime powder (binder) are found to be higher than the ordinary Portland cement. The compressive strength of mortar prepared from lime, fly ash and GGBFS was low during early stages of curing, but it achieved almost the same strength as of normal cement mortar after 56 days. The compressive strength of mortar cubes made from lime, fly ash, GGBFS in the proportion of (35:65:300) was found to be 15.6 N/mm^2 at 28 days and 38.8N/mm^2 at 60 days. Whereas, the mortar with proportion (35:65:200) it was 13.53 N/mm^2 at 28 days and 35.4 N/mm^2 at 60 days of curing. The 28 days compressive strength of concrete of steel slag hydrated matrix is found to be less than the normal cement concrete. The compressive strength of SSHM after 28 days of curing was found to vary from 9N/mm^2 to 13N/mm^2. However, other researchers have found the compressive strength of SSHM in the range of 20 N/mm^2 to 30 N/mm^2 after 28 days of curing. Flexural strength of steel slag hydrated matrix is lower than the normal concrete. However, the split tensile strength is approximately same as the normal concrete. Steel slag hydrated matrix has the features like made from 100% recycled resources, same strength performance as ordinary concrete. It involves no burning of fossil fuels, which is otherwise used for manufacturing of cement, helps in checking emission of CO_2 and protects environmental pollution.

LIST OF SYMBOLS

The principal symbols used in this thesis are presented for easy reference .A symbols is used for different meaning depending on the context and defined in the text as they occur.

SYMBOLS

SSHM	Steel slag hydrated matrix
GGBFS	Ground granulated blast furnace slag
SS	Steel slag
W	Water
p	Powder
c	Cement
M	Bending Moment
Z	Section Modulus
b	breadth
h	height
CPCB	Central pollution control Board
d	lattice spacing
Greek symbol	
σ_{SP}	Split tensile stress
λ	wave length of x-ray
θ	glancing angle

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CHAPTER 1

INTRODUCTION

Chapter-1

INTRODUCTION

Global warming and environmental destruction have become the major issue in recent years. Emission of host of green house gases from industrial processes and its adverse impact on climate has changed the mind set of people from the mass-production, mass-consumption, mass-waste society of the past to a zero-emission society, utilization of industrial wastes and conservation of natural resources. Preventing the depletion of natural resources and enhancing the usage of waste materials has become a challenge to the scientist and engineers. A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material. The two major by-products of industry are slag and fly ash. In India, the annual production of fly ash is about 170 million tons, but about 35 percent of the total is being utilized, which is very low. Owing to its ultra fineness, pozzolanic contribution and other properties, the use of fly ash makes a cost of disposal and to reduce environmental pollution, it is an imperative to increase the quantity of fly ash utilization. Similarly, the Steel industry in India is producing about 24 million tones of blast furnace slag and 12million tones of steel slag.

Concrete is the most preferred and the single largest building material used by the construction industry. Concrete is basically made of aggregates, both fine and coarse, glued by a cement paste which is made of cement and water. Each one of these constituents of concrete has a negative environmental impact and gives rise to different sustainability issues. The current concrete construction practice is unsustainable because, not only it consumes enormous quantities of stones, sand, and drinking water, but also one billion tons a year of cement, which is not an environment friendly material. For production of cement huge amount of energy is needed and about 8 % of CO_2 is released to atmosphere during cement production. In fact, many by-products and solid wastes can be used in concrete mixes as aggregates or cement replacement, depending on their chemical and physical characterization, if adequately treated. The steel industry slag having desirable qualities and can be used as coarse aggregates in concrete construction. Graf and Grube have reported that the Ground granulated blast furnace slag cured properly has lower permeability .The incorporation of fly ash and blast furnace slag in concrete leads to many technical advantages. When two mineral admixtures are used together, better results can always achieve. The use of such industrial by-product or waste material having desirable qualities can result in saving of energy and conventional materials. With increase in population, the demand for construction of residential and public buildings is also increasing. The iron and steel industry produces extremely large amounts of slag as by-product of the iron making and steelmaking processes. As useful recycled materials, iron and steel making slag are mainly used in fields related to civil engineering, for example, in cement, roadbed material, and concrete aggregate. Their recycling ratio is close to 100%, making an important contribution to the creation of a recycling-oriented society. However, public works projects, that is strongly related to recycled fields, tend to be reduced recently and, moreover, other recycled materials, such as reused roadbed materials and fly ash, become competitor of slag in the fields. Thus, the development of new application technologies has become an urgent matter.

The JFE Steel Group has developed and sells the following as new use technologies for iron and steel making slag: (1) an environment-friendly block, “Ferroform,” which can be used as a substitute for concrete, (2) materials for restoration of coastal and marine environments, “Marine Block” and “Marine Base,” and (3) a water retaining pavement material which reduces the urban heat island phenomenon. This report introduces these new application technologies of iron and steel making slag which are contributing to a recycling-oriented soci- steel slag was considered a waste material having no economic asset, but nowadays it is known that 100 percent of blast furnace slag and 75-80 percent of steel slag can be reused. A large amount of steel slag was deposited in slag storing yards which occupied farmland, silted rivers and polluted the environment for many years. Steel slag is produced as a by-product during the oxidation of steel pellets in an electric arc furnace. This by-product that mainly consists of calcium carbonate is broken down into smaller sizes. One way to utilize the steel slag is to incorporate it into hot mix asphalt (HMA). Steel slag aggregate has been used in asphaltic mixtures since the early 1970's in Canada. This process has been used successfully in the Midwestern and eastern United States with reported improvement in pavement performance. Their experiences indicate that the addition of steel slag may enhance the performance characteristics of the pavement. Since the slag is rough, the material improves the skid resistance of the pavement. Also, because of the high specific gravity and angular, interlocking features of the crushed steel slag, the resulting HMA is more stable and resistant to rutting. Steel slag has been used to construct pavements for nearly one hundred years. Since it was discovered that the residue from the manufacture of steel could be crushed and processed into a product that looked like crushed rock, other testing was performed to determine the usefulness of this “waste” product. It was discovered that the highly angular, rough textured, vesicular, pitted surfaces provide the particle interlock. Now days it is used as coarse aggregate in concrete. The present work aims at developing a cementation material that can replace the conventional cement in concrete work using the waste product like fly ash, granulated blast furnace slag with hydrated lime without involving the burning process and manufacture, quality assessment of eco-friendly concrete that is made out of the above material and steel slag as coarse aggregate. This will solve the problem of waste disposal side by side preserving our natural resources.

CHAPTER 2

LITERATURE REVIEW

Chapter2

LITERATURE REVIEW

2.1 INTRIDUCTION

Preventing the exhaustion of natural resources and enhancing the usage of waste materials has become a significant problem of the modern world. Million tons of waste materials come into being as a result of within a year. A limited number of studies have been done concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material. Fortunately we have just such a material - concrete, and most of the essential research has been done to enable concrete to fill this role. The use of SSHM as a replacement to conventional concretes us of recent origin. It uses mostly the waste products of industries in addition to that its production requires no burning of fossils fuels thus no emission of polluting gasses like CO_2 and SO_2 etc. This chapter reviews the work done by previous investigator regarding the manufacture of SSHM and its properties.

2.2 STEEL SLAG

Extraction of 'iron' from ores is a complex process requiring a number of other materials which are added as flux or catalysts. After making steel these ingredients forming a matrix are to be periodically cleaned up. Removed in bulk, it is known as steel –slag. It consists of silicates and oxides. Modern integrated steel plants produce steel through basic oxygen process. Some steel plants use electric arc furnace smelting to their size. In the case of former using oxygen process, lime (CaO) and dolomite (CaO.Mgo) are charged into the converter or furnace as flux. Lowering the launce, injection of higher pressurized oxygen is accomplished. This oxygen combines with the impurities of the charge which are finally separated. The impurities are silicon, manganese, phosphorous, some liquid iron oxides and gases like CO_2 and CO. Combined with lime and dolomite, they form steel slag. At the end of the operation liquid steel is poured into a ladle. The remaining slag in the vessel is transferred to a separate slag pot. For industrial use, different grades of steel are required. With varying grades of steel produced, the resulting slags also assume various characteristics and hence strength properties. Grades of steel are classified from high to medium and low depending on their carbon content. Higher grades of steel have higher carbon contents. Low carbon steel is made by use of greater volume of oxygen so that good amount carbon goes into combination with oxygen in producing CO_2 which escapes into atmosphere. This also necessitates use of higher amount of lime and dolomite as flux. These varying quantities of slag known as furnace slag or tap slag, raker slag, synthetic or ladle slag and pit or clean out slag. Fig-2.1 presents a flow chart for the operations required in steel and slag making.

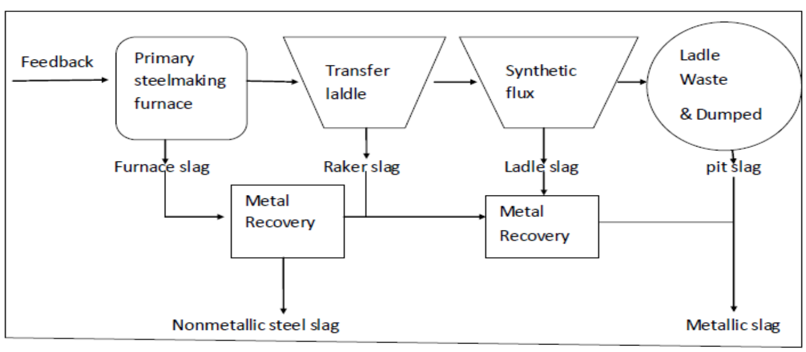

Fig-2.1 Flow chart of steel slag production

The steel slag produced during the primary stage of steel making is known as furnace slag or tap-slag which is the major share of the total slag produced in the operation. After the first operation, when molten steel is poured into ladle, additional; flux is charged for further refining. This produces some more slag which is combined with any carryover slag from first operation. It helps the in absorbing of deoxidation products, simultaneously providing heat insulation and protection of ladle refractories. Slag produced on this operation is known as raker and ladle slag.

Utilization of slag:

The steel slag is used as aggregates. Natural aggregate resources are becoming more difficult to develop or remove aggregate from the ground when slag can be used as a substitute which reduce waste and conserve resources. It protects and preserves our environment. Benefit from technical advantages offered by many of the steel making slags. High performance products not necessarily low grade applications

2.3GGBS

Blast furnace slag is a by-product from the manufacture of iron in a blast furnace. The liquid iron blast furnace is lighter in weight than the main product which is iron in a molten state. The blast furnace will naturally separate from the iron where it is collected and cooled with large amount of cold water. This quenching process results in the transformation of liquid into small sized particles having amorphous particles' structure. Following an efficient drying process, the particles are ground to the desired fineness and the material gain a cementitious property. The main chemical composition of GGBFS is SiO_2 Al_2O_3 and CaO. When GGBFS is added to concrete in powered form it accelerates the pozzolanic reaction. The benefits of adding powered GGBFS in concrete can be grouped as follows:

Improvement of fresh concrete properties

The impacts of GGBS addition on the behavior of fresh concrete are as follows:

- Increased cohesion
- Reduced internal and external bleeding
- Reduced risk of segregation
- Reduced washout for under water concrete
- Enables the production of self compacting concrete.

Improvement of hardened concrete properties:

The impacts GGBS addition on hardened concrete performance is as follows:

- Increased tensile and flexure strength
- Enables production of high performance concrete
- Enhanced resistance to chloride attack, sulphate attack,
- Acid attack and various other external chemical attacks
- Enhanced resistance to internal chemical attacks such as
- Alkali silica reaction and alkali carbonate reaction
    - Improved impermeability to liquids, gases and ions
    - Improved bonding between concrete and steel reinforcement
    - Reduced risk of cracking due to thermal stresses.

2.4 FLY ASH

In many disposal areas, fly ash is hauled from the plant and disposed loose by tailgating over the edge of fly ash slope. The resulting embankment is often unsightly and costly to remain steep fly ash slopes and lack of adequate drainage often result in slides, which encroach upon resulting properties, cause erosions and silts up nearby streams. In wet disposal system, ten fly ash and bottom ash are mixed with sufficientter and the ash slurry is sluiced into large sized ponds called ash ponds. This ash is called pond ash or Fly ash.

USE OF FLY ASH

- Fly ash can be used for multifarious applications Some of the application areas are the following Brick manufacturing
- Cement manufacturing Part replacement in mortar and concrete.
- Road and embankment construction
- Dyke rising.
- Structural fill for reclaiming low areas.
- Stowing material for mines.
- Agriculture and Forestry.

2.5LIME

The most common form of commercial lime used in concrete is slaked lime and unsliced lime also used. Quick lime is higher lime (CaO or $CaO.MgO$) content than hydrated lime but it is much more dangerous than hydrated lime and strict safety precautions are necessary when it is used.

Classification of Lime by I.S.I

Indian Standards institute has classified the lime into 3 parts i.e., Class A, B & C. Class A is used for masonry work and can be obtained only in the form of slaked lime. Slaked lime must be the form of powder. Class B is used for mortar where as class C is used for plaster & white washing. Class C is infecting pure lime. Class B & C can be obtained in the form of slaked or unsliced lime Unsliced lime may contain calcium oxide and little amount of magnesium oxide.

2. 6 BRIEF REVIEW OF VARIOUS STEL SLAG HYDRATED MATRIX

In this section a brief review of the available literature regarding steel slag hydrated matrix are presented.

In Dec. 1999, JEF Steel’s developed the concrete using waste material such as steel making slag, ground granulated blast furnace slag, fly ash &lime dust and 5 t type breakwater blocks approximately 2.0 m in height were manufactured from steel slag hydrated matrix and concrete. These blocks were exposed in the tidal at Mizushima Port, Okayama Pref. in Seto - Inland Sea in Feb. 2000. Square sections of biofouling organisms with an area of 20 cm x 20 cm were cut respectively from four locations on the wave-dissipating blocks and dried at 60°C for 24 h. The biomass of the specimens was then measured.

Mathur et al. (1999) looked at the physical properties of blastfurnace slag and steel slag and concluded that both materials were suitable to replace natural stone aggregates in base and sub base road layers, as long as the steel slag was adequately weathered. The study also mixed various slogs together and determined that a mixture of ACBF slag (50%), steel slag (20%), granulate blast furnace slag (20%), fly ash (6%), and lime (4%) would self-stabilize over time and form an adequate bound base or sub base road layer. They have got that the concrete containing above these material better corrosion resistances.

Artificial stones and cover blocks using steel slag hydrated matrix were manufactured and placed in a shore protection repair project at JFE Steel's West Japan Works (Kurashiki) between Sept. 2000 and Sept. 2002.

H.Matsunaga et al (2000) have taken the mixture proportion of steel slag making ground granulatrd blast furnace slag, fly ash, water and small amount of an activator (calcium hydroxide or lime dust). Cement and natural aggregate were not used. The physical properties of steel slag hydrated matrix were measured. The compressive strength of steel slag hydrated matrix products increases with curing time and exceeds 18N/mm2, which is the general design strength of breakwater blocks. Compared the compressive strength at 91 days and 28 days strength is approximately 1.3 times greater with extended curing. That is the compressive strength of steel slag hydrated matrix increases with longer curing periods and achieves a level higher than that of an ordinary concrete with long term.

Tatsuhito Takashashi and Kazuya Y abuta (2002) have study on the steel making slag and granulated blast furnace slag (GGBS). Availability of natural sand is decreasing year by year, for this serious problem they have used ground granulated slag (GGBS) which is named as BF slag sand or Sandy-S. In concrete they used as fine aggregate in place of natural sand.

Haruyoshi Tanabe and Masayki Nakada (2003) developed the marine block .They have prepared the mixture of steel making slag , ground granulated blast furnace slag ,lime and fly ash made the marine blocks , this blocks carbonated and reacted with carbon dioxide gas . They have used to pile on the sea bottom for investigating their effect on cultivating seaweed and other marine organisim.

M. Maslehuddi et al. (2003), have particularly worked in areas where good-quality aggregate is scarce. Their research study was conducted to evaluate the mechanical properties and durability characteristics of steel slag aggregate concrete in comparison with the crushed limestone stone aggregate concrete. The durability performance of both steel slag and crushed limestone aggregate concretes was evaluated by assessing by water permeability, pulse velocity, dimensional stability and reinforcement corrosion. The results indicated that the durability &characteristics of steel slag cement concretes were better than those of crushed limestone aggregate concrete.

Takashi FUJII, Toshiki AYANO and Kenji SAKATA(2004) were study on the concrete Steel-slag hydrated matrix which is made of ground granulated blast furnace slag powder and steel-making slag and are by-product of iron manufacturing. Alkali activator is added if necessary. The cement is not required to produce the steel-slag hydrated matrix. The leaching of heavy metal from steel-slag hydrated matrix is very little. This type construction material is called environmental conscious material in Japan. This research presented that the strength of steel-slag hydrated matrix depend on pH of steel-slag hydrated matrix after mixing. By controlling pH of steel-slag hydrated matrix after mixing, dispersion of strength become small and it can be stably made the same grade as cement concrete. It is also clear that the resistance to carbonation and steel rod corrosion of steel-slag hydrated matrix has high performance for a long time by alkalinity of steel-making slag.

H. MOOSBERG-BUSTNES (2004) has studied on properties of steel slag and investigate if it is possible to improve the steel-slags properties, by selective screening, fine wet grinding or remelting, so that the steel-slags can be used as mineral-addition/filler material in concrete.

Three different studies were conducted:

1 .The effect of the fines of disintegrating AOD-slag on concrete strength was examined.

2. The effect of wet ground EAF- and AOD-slogs on cement pastes' heat development, concrete strength and shrinkage/expansion were examined.

3. Remelting and granulation of AOD-, EAF- and ladles lags and their effects on cement hydration were examined (part of a joint MiMeR-project).

They found the result; the compressive strength for mortar containing fines of disintegrating AOD-slag obtains a slightly increased strength compared with the reference samples containing quartz. This effect may be due to the filler effect or because a positive chemical effect takes place.

Kyong Yun Yeaua, Eun Kyum Kimb(2005) have presented the experimental test results on corrosion resistance of concrete containing ground granulate blast-furnace slag (GGBS) and ASTM Type I or ASTM Type V cement. To investigate the problem, a series of tests were performed.

They First, rapid chloride permeability tests were carried out in accordance with ASTM C 1202 to determine the qualitative terms of chloride-ion penetrability, accelerated chloride-ion diffusion tests were done to calculate diffusion coefficients of chloride-ions permeated through concrete specimens. Steel corrosion tests were carried out by using the repeated wetting and drying technique, half-cell potential tests were implemented in accordance with ASTM C 876 to evaluate the probability of steel corrosion. Finally, the surface area of corrosion on embedded steel in concrete specimens was measured to confirm half-cell test results. Test results shown that the coefficient of permeability of Type I cement concrete was lower than that of Type V cement concrete. All the concrete mixed with GGBS exhibited lower diffusion coefficient, compared to GGBS-free concrete. Moreover, the corrosion probability of steel bar in Type V cement concrete was higher than that of steel bar in Type I cement concrete. Based on the test results, it is suggested the compressive strength of all compressive specimens exceeded design strength of 35 MPa before 28 days. Their results indicated that GGBS mixture specimens showed lower compressive strength than B1 mixture ones at the early age, the compressive strengths of GGBS mixtures were stronger than that of B1 mixture after 28 days. The permeability of Type I cement blended with GGBS was lower than that of Type V cement. The chloride-ion concentrations of Type I cement are lower than that of Type V cement, compared for the same amount of GGBS.

Tomonari Kimura and Nobuaki Otskui (2006) have developed, Steel Slag Hydrated Matrix (SSHM) as a construction material for reducing environmental problems. They have investigated on pre-treatment slag and blast-furnace slag powder which are by-products of steel making process. In SSHM, the corresponding substitute material for cement is the mix of blast-furnace slag powder, fly ash and slaked lime whiles the corresponding substitute material for the fine and coarse aggregate is pre treatment slag..

They discussed the prediction of deterioration due to chloride attack when SSHM is used as material with reinforcing steel under marine environment. In order to predict the deterioration of steel reinforced members due to chloride attack, it is basic to determine the length of time for each deterioration stage: the incubation period, the propagation period, the acceleration period, and the deterioration period.

Their results indicated that ,the incubation period was calculated using the chloride ion diffusion coefficient of the specimens cured for four weeks , the generalized equation of the Flick's second law and the chloride concentration limit of 1.2kg/m^3 around the steel bar (JSCE). While the propagation period was calculated by using results of mass reduction due to corrosion, the equation from JCI-SC1 for mass loss in mg/m^2/day and the corrosion mass limit of 10mg/cm2 which is generally used as the quantity of corroded mass of steel at the occurrence of crack (JSCE), shows the calculation result of the average ratio of deterioration periods between SSHM and normal concrete.

The results show that SSHM had longer periods of incubation and propagation compared with concrete. This shows that the use of SSHM as substitute to concrete in steel-reinforced structures under chloride attack is quite feasible and also the service life of the structure possibly becomes longer.

Takshi Fujii ,Toshiki Ayanond and Kenji Sakta (2007) have developed the concrete using steel making slag which is reducing environmental load. They have made the concrete using Ground granulated blast furnace slag (GGBS),lime dust(LD),steel making slag(SS),high range water reducing admixture (HRWRA) and Air entraining agent (AE).Their result indicted that low resistance to freezing and thawing of the steel making slag concrete was due to small amount entrained air by the agent and adequate quantity of fly ash is necessary to consume calcium hydroxide around the aggregate.

Hanifi Binice et al. (2007) The aim of this research work is to investigate the seawater resistance of the concrete incorporating ground blast furnace slag (GBS) and ground basaltic pumice (GBP) each separately or both together. The variable investigated in this study is the level of fine aggregate replacement by GBS and GBP and normal concrete Compressive strength measured on 150 mm cubes was used to assess the changes in the mechanical properties of concrete specimens exposed to seawater attack for 3 years. From this study, they observations were found , GBP concrete presented an excellent behavior in both short and long-term compressive strength in seawater, higher compressive strengths and lower permeabilities. Abrasion resistance of concrete was strongly influenced by its compressive strength and GBS and GBP content then the normal concrete.

Nobuaki et.al (2006), have developed a new construction material called “steel slag hydrated matrix”, hereafter this term will be abbreviated as SSHM, produced from steel making slag, ground blast furnace slag powder without using portland cement and natural gravel. However, its application has been limited to non-steel reinforcement material when used in structures under marine environment. They applied SSHM for steel reinforced structures and their results showed that the resistance to chloride ion penetration, oxygen permeability, resistance of steel bar to corrosion in SSHM were equal to or even better than that of steel reinforced concrete material under marine environment.

2.7 SCOPE OF THE PRESENT STUDY

Thus, through the appraisal of the literature review it is observed that several attempts have already been made by researchers to understand the mechanism of Steel slag hydrated matrix or steel making slag concrete. However, in the present study an attempt has been made to concrete which is containing full of waste material.

Hence, the experimental programme undertaken investigates:

1. To determine the mix proportion of fly ash, lime, ground granulated blast furnace slag and water to achieve the aim study

2. To determine the water/ (lime fly ash) ratio so that design mix adequate proper workability.

3. To determine the mix proportion of fly ash, lime, ground granulated blast furnace slag, steel slag and water to achieve the required strength.

4. To investigate different basic properties such as compressive strength, flexural strength etc. of Steel Slag Hydrated Matrix in comparison with ordinary concrete.

5. To study the effect of curing period of the strength characteristics of SSHM.

CHAPTER 2

LITERATURE REVIEW

CHAPTER 3

EXPERIMENTAL STUDY

Chapter-3

EXPERIMENTAL STUDY

3.1 INTODUCTION

In this present study a series of experiments have been done to evaluate the characteristic strength of steel slag hydrated matrix. The objective of this study is to prevent the exhaustion of natural resources and enhancing the usage of waste materials, concern about global environmental issues, and a change over from the mass-production, mass-consumption, mass-waste society to a zero-emission society. The physical and chemical properties of the raw materials have been studied to characterize the raw materials. In addition to this tests have been conducted in two phases. In first phase of tests the optimum percentage of lime is determined by testing mortar cubes prepared from lime+ fly ash as binder and GGBFS as fine aggregate in ratio of 1:2 and 1:3 with 20, 35, 50, 65, and80 percent lime in the binder. In the second series of tests concrete specimens were prepared by mixing lime +fly ash binder, GGBFS and steel slag in the ratios of 1:1.5:3. The compressive strength, flexural strength and split tensile strength of these samples were determined after 7 and 28 days.

The Physical properties, chemical properties of materials have been study such as

- Gradation of fine aggregate and coarse aggregate
- Abrasion resistance strength of Aggregate.
- Water absorption of Fine aggregate and coarse aggregate.

- Specific gravity of these above material.
- XRD and SEM analysis of these above materials.

3.2 MATERIALS USED

3.2.1 Fly ash

The fly ash used in the present investigation was collected from Rourkela steel plant, Sundargarh, district of Orissa. The fly ash had grayish white colour. The chemical, morphological, mineralogical and physical data for the above fly ash is presented as follows. The tests on fly ash were carried out as per IS: 1727-1967. The specific gravity of fly ash is 2.25 and fineness is 8 % (by dry sieving method).

Chemical analysis

Fly ash consists of silica, alumina, oxides of iron, calcium and magnesium and toxic heavy metals like lead, arsenic, cobalt, and copper. The chemical composition of fly ash is given in the Table 3.3. The permissible value as per IS: 3812-1981 and ASTM standard also shown here.

Table 3.1Chemical composition of fly ash

Type	Fly ash (Present study) (%)	ASTM requirement C-618 Class F (%)	I.S. specifications (%)
SiO_2	56.04	-	35 (minimum)
Al_2O_3	33.85	-	
Fe_2O_3	3.90	-	
$SiO_2 + Al_2O_3 + Fe_2O_3$	93.84	70.00 minimum	70.0 (minimum)
CaO	0.73	-	
MgO	0.68	5.00 maximum	5.0 (maximum)
K_2O	1.22		
Na_2O	0.19	1.50 maximum	1.5 (maximum)
TiO_2	2.69	-	
MnO_2	0.31	-	
SO_3	0.05	5.00 maximum	3.0 (maximum)
L.O.I (900^{o}C)	1.40	6.00 maximum	5.0 (maximum)

The fly ash meets the general requirements of ASTM C-618 Class F fly ash and as per IS: 3812-1981 found suitable as a pozzolanic material. The chemical composition of fly ashes worldwide is presented in Table 3.4.

Table 3.2 Chemical composition of fly ashes from different countries (*data sources: Sridharan et al., 2001h*)

Sl. No.	Country	Compounds by weight ; %				
		SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**LOI**
1	Australia	44-73	16-33	3-6	0-9	1-9
2	Canada	37-59	12-24	3-39	1-13	0-10
3	China	44-55	20-32	6-17	5-9	3-9
4	Germany	48	25	7	3	-
5	Hong Kong	38-77	14-46	1-18	0-16	4-8
6	**India**	**38-65**	**16-44**	**3-20**	**0-4**	**0-20**
7	Japan	50-62	22-30	4-7	3-7	1-6
8	Poland	43-52	19-34	1-13	2-9	2-10
9	South Africa	40-53	24-35	5-11	5-10	2-11
10	Thailand	27-34	19-28	20-24	11-16	0-2
11	UK	37-54	17-33	6-22	1-27	0-27
12	USA	28-59	7-38	4-42	0-13	0-48
13	**Present study**	**56.04**	**33.85**	**3.9**	**0.725**	**1.4**

LOI-Loss on ignition at $900^{o}C$

Scanning electron microscope (SEM)

Particle morphology of the fly ash was investigated using Scanning Electron Microscope (SEM). SEM is used to scan a specimen with a finely focused beam of kilovolt energy. An image is formed by scanning cathode ray tube in synchronism with the beam and by modulating the brightness of this tube with beam excited signals. In this way an image is built-up point by point which shows the variation in the generation and collection efficiency of chosen signals at different points on the specimen. By using different condition and specimens, it is possible to obtain image showing the surface topography, surface potential distribution, magnetic domains, crystal orientations and crystal defects in specimen. In this study the Scanning-Electron-Microscope (SEM) used a JEOL-JSM-6480 LV microscope with an oxford EDS micro analysis. The microstructure and distribution of fly ash samples were studied. Micro-photographs of the sample are shown in Fig. 3.1 and 3.2. It is clearly observed that most of the particles are spherical structure with few irregular particles. The surfaces of spherical particles are found to be smooth as it is a low calcium fly ash (Diamond 1986 and Das 2003) with particle size varying from 1μm to 25μm.

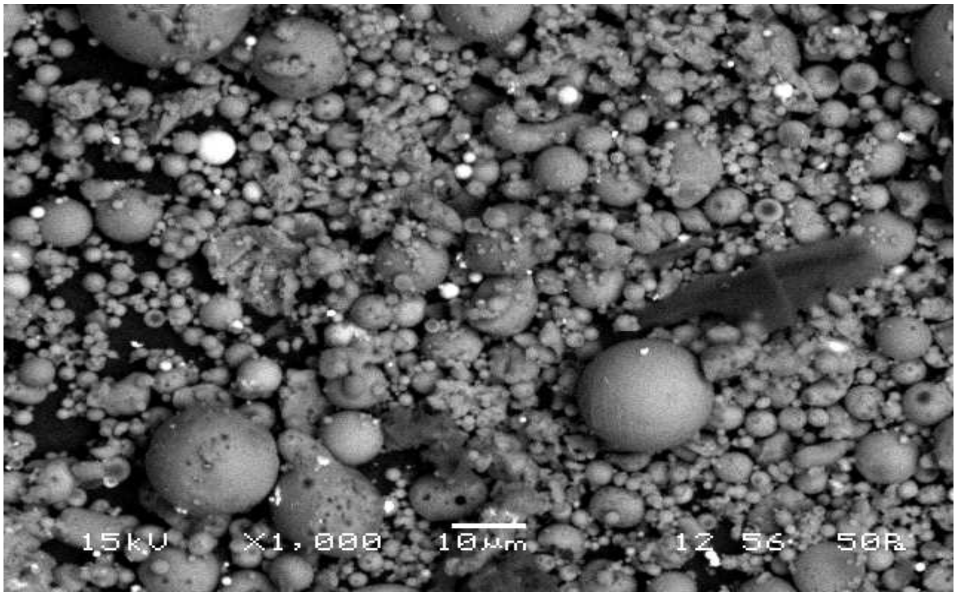

Fig: 3.1 Microstructure of fly ash

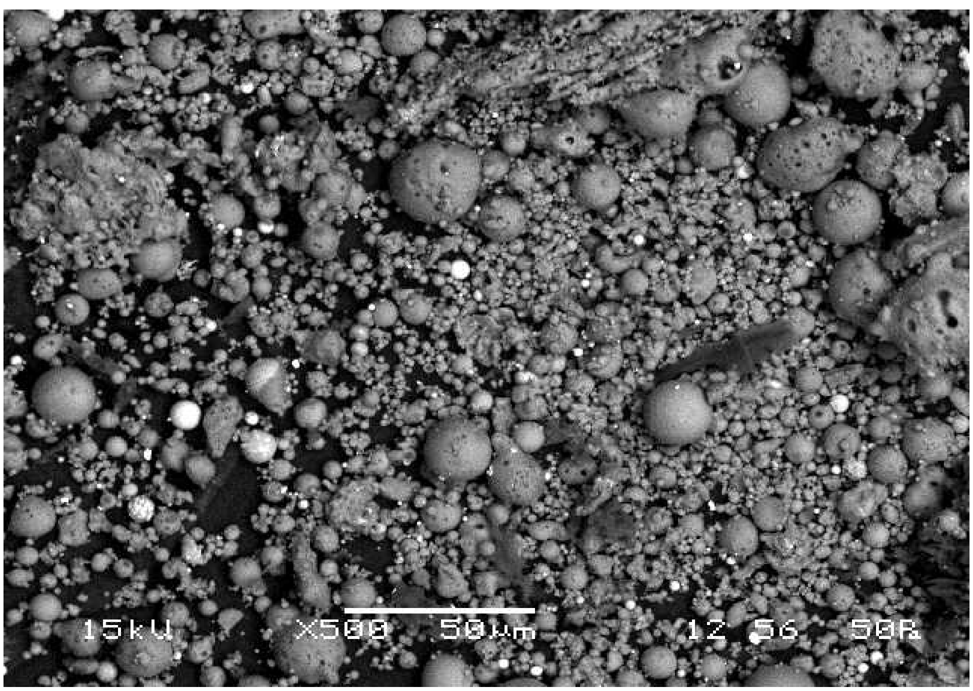

Fig. 3.2. Microstructure of fly ash

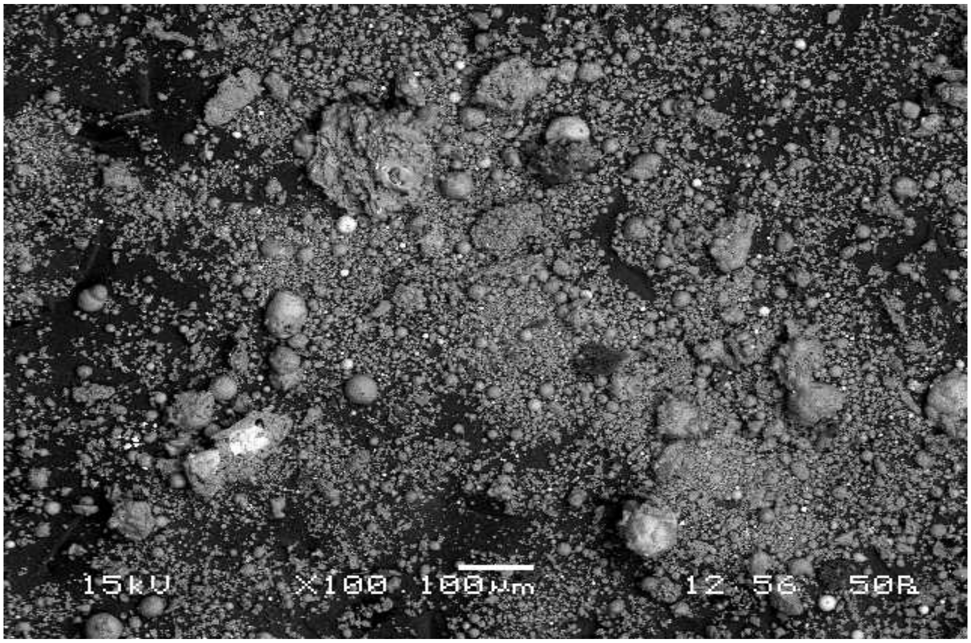

Fig. 3.3. Microstructure of fly ash

The grain size distribution curve of fly ash is shown in Fig. 3.3. The general range of the fly ashes,world wide are shown as the upper and lower boundary therein.

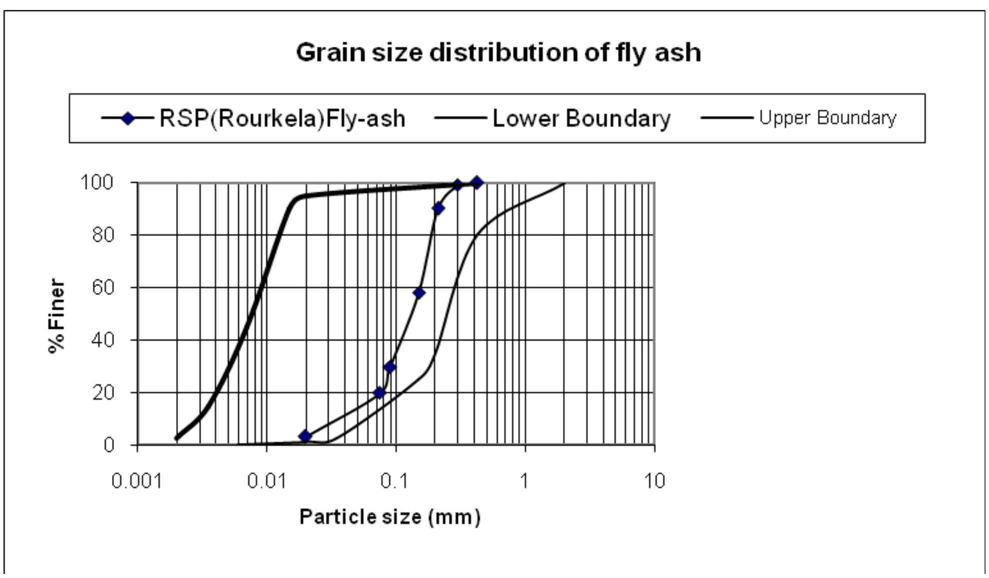

Fig. 3.4 Grain size distribution of fly ash

X-ray diffraction test

The X-ray diffraction (XRD) test was used to determine the phase compositions of fly ash particles. The basic principles underlying the identification of minerals by XRD technique is that each crystalline substance has its own characteristics atomic structure which diffracts x-ray with a particular pattern. In general the diffraction peaks are recorded on output chart in terms of 2θ, where θ is the glancing angle of x-ray beam. The 2 θ values are then converted to lattice spacing ‘d’ in angstrom unit using Bragg’s law.

$$d = \frac{\lambda}{2n\,\mathrm{Sin}\theta}$$

where n is an integer

λ = wave length of x-ray specific to target used.

The XRD test result of fly ash sample is shown in Fig.3.4. From the figure it can be observed that quartz and mullite are predominantly present. This is similar to previous study for low calcium fly ash (Diamond 1983, Das and Yudhbir 2003).

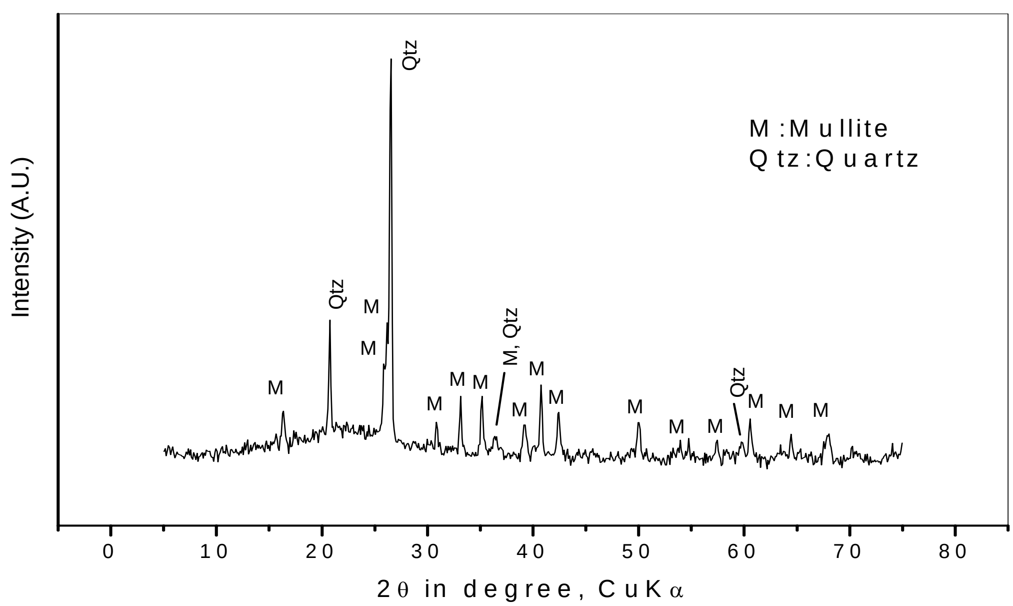

Fig. 3.5X-ray diffraction of fly ash dust

3.22 Steel slag:

This is the main ingredient of steel slag hydrated matrix (SSHM). In our research program we have used the locally available steel slag. The Steel slag used in the present investigation was collected from Rourkela steel plant, Sundargarh, district of Orissa. The steel slag had grayish white colour. The chemical, morphological, mineralogical and physical data for the above steel slag is presented as follows. The tests on steel slag were carried out as per IS: 1727-1967. The specific gravity of fly ash is 2.98 and it comes under Zone-II (by IS: 12020-1982). This material replaces the coarse aggregate in normal concrete.

The different physical and chemical properties of steel slag are given below.

Table 3.3 Physical properties of coarse aggregate

Aggregates	Absorption (%)	Bulk Specific Gravity	Los Angeles Abrasion(%)
Lime Stone	0.4	2.73	39
Steel slag	0.6	2.98	35

Steel Slag is found in the form of big pebbles. It is crystalline in microstructure and non-hydraulic in nature. The microstructure and distribution of steel slag was studied. Micro-photographs of the sample are shown in Fig. (3.6-3.9) and fig (3.10). From the figure it can be observed that quartz iron oxide aluminum oxide and various silicates are predominantly present. It is clearly observed that most of the particles are spherical structure with few irregular particles. The surfaces of spherical particles are found to be irregular and round as it is a high calcium steel slag (Central pollution control Board 2006, and T Sowmya and S. R Sankaranarayaanan.2004) with particle size varying from 0.075μm to 80m. However the present case steel slag passing through IS sieve 20mm is used for making SSHM blocks. The chemical composition was given below.

Table 3.4 Chemical composition of Steel slag:

Composition	Steel slag Present study (%)	CPCB
Fe	18	14.22
Cao	34	34.32
SiO	15	14.22
MgO	2	5
Al_2O_3	4	4.17
P_2O_5	5	5.6
MnO	4	4.5

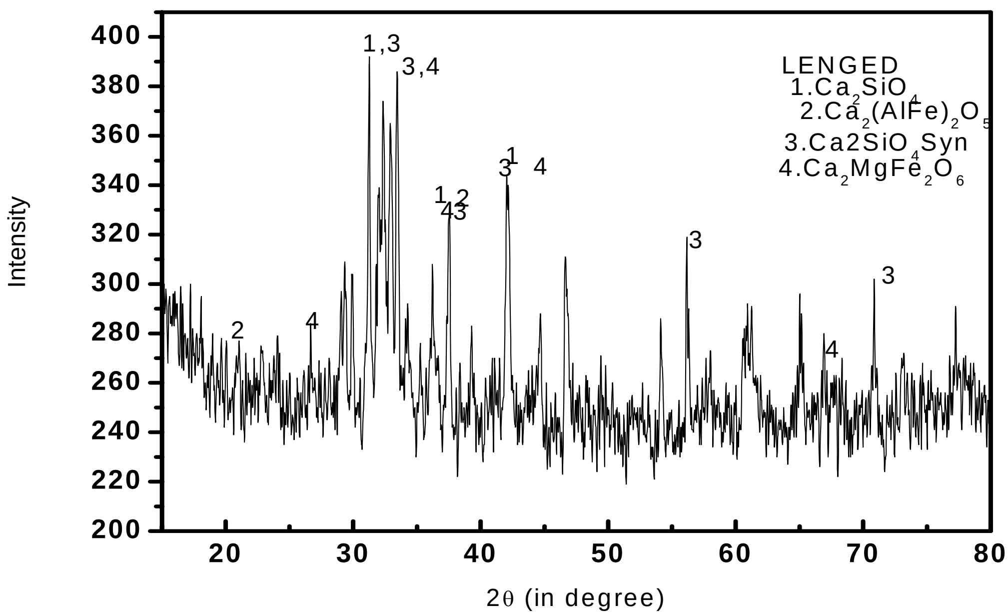

Fig. 3.6 X-ray diffraction of steel slag

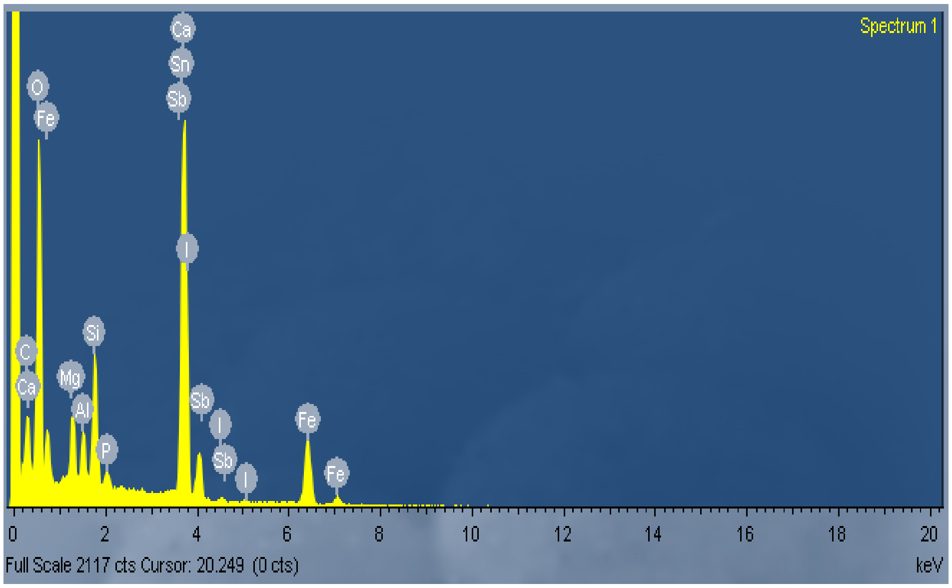

Fig 3.7: Microscopic pattern of steel slag

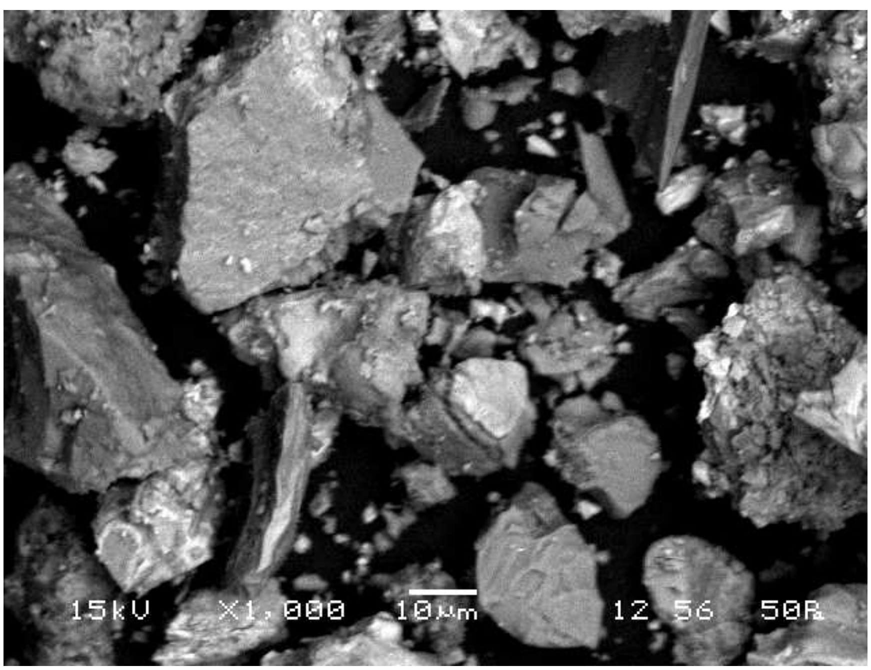

Fig: 3.8 Microstructure of steel slag

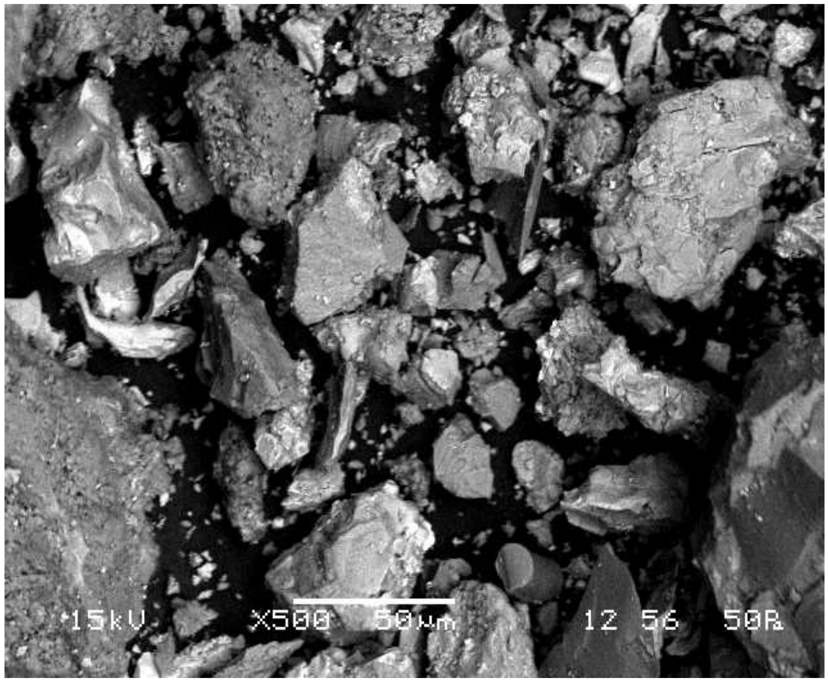

Fig: 3.9 Microstructure of steel slag

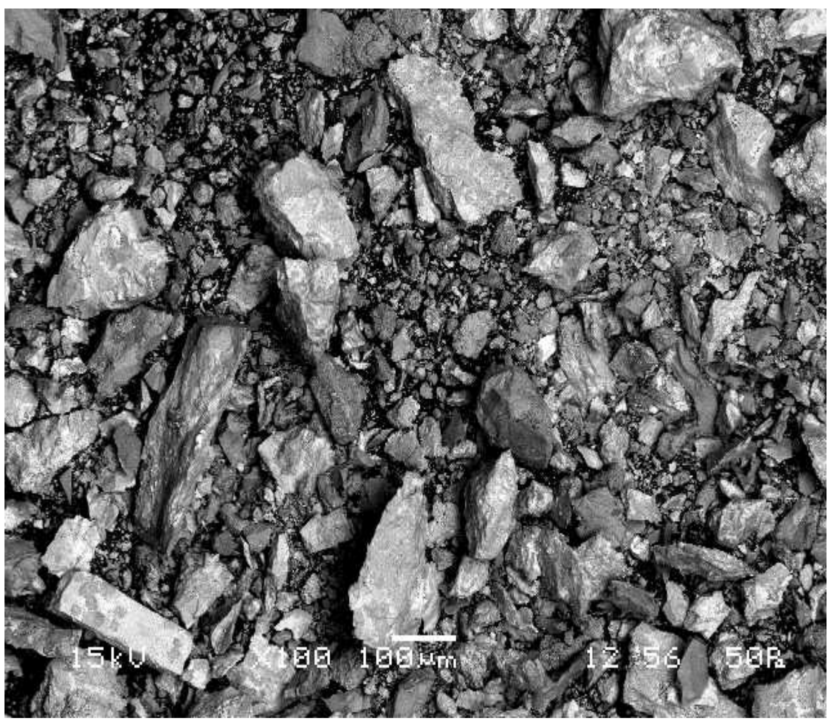

Fig:10 Microstructure of steel slag

3.23 Ground granulated blastfurnace Slag (GGBFS)

The Ground Granulated Blast Furnace Slag used in the present investigation was collected from Rourkela steel plant, Sundargarh, district of Orissa. The Ground granulated blast furnace slag had off white colour. The chemical, morphological, mineralogical and physical data for the above ground granulated blast furnace slag is presented as follows. The tests on ground granulated blast furnace slag were carried out as per IS: 12089-1987.The different physical and chemical properties of ground granulated blast furnace slag are given below.

Table 3.5 Physical properties of fine Aggregate

Fine Aggregate	Water absorption (%)	Specific Gravity
Ground granulated Blast furnace Slag	1.4	2.17
Natural sand	0.96	2.7

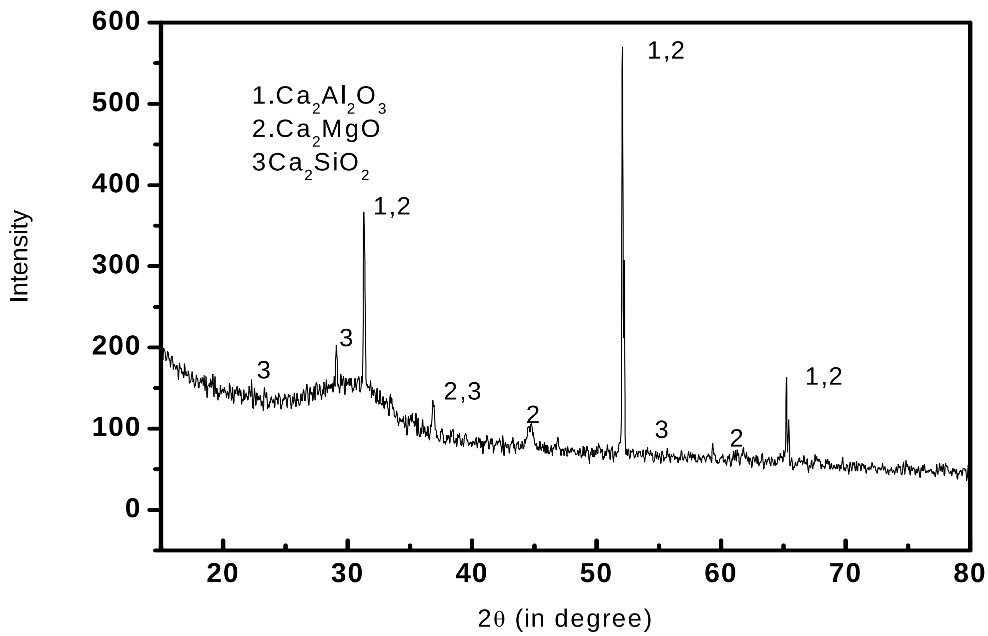

Fig. 3.11 X-ray diffraction of ground granulated blast furnace slag

The XRD test result of Ground Granulated blast Furnace slag sample is shown in Fig.3.11. From the figure it can be observed that quartz iron oxide aluminum oxide and various silicate are predominantly present. This is similar to previous study for high calcium GGBFS (Central pollution control Board 2006, and T Sowmya and S. R Sankaranarayaanan.2004). The chemical composition was given below.

Table 3.6 Chemical Composition of GGBFS

Composition	GGBFS Present Study(%)	CPBC
Fe	0.4	0.82
CaO	39	40
SiO_2	33	33.41
MgO	7	8.86
P_2O_5	13	12
Al_2O_3	19.5	20.05
MnO	0	0

The microstructure and distribution of ground granulated blast furnace were studied. Micro-photographs of the sample are shown in Fig. (3.12-3.14) and fig 3.15. It is clearly observed that most of the particles are spherical structure with few irregular particles. The surfaces of spherical particles are found to be porosity with high calcium (yuksel, Isa 2006 and Sanjay Kumar[1], S. Badjena[1]) with particle size varying from 0.075mm to 7mm. In the present case ground granulated blastfurnace is passing through IS sieve and size0- 4.75 mm is used for making SSHM blocks.

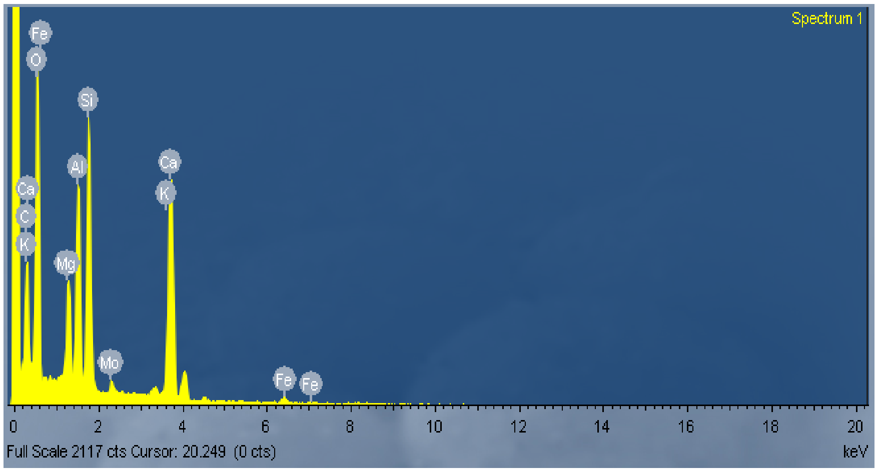

Fig: 3.12.Microscopic pattern of GGBS

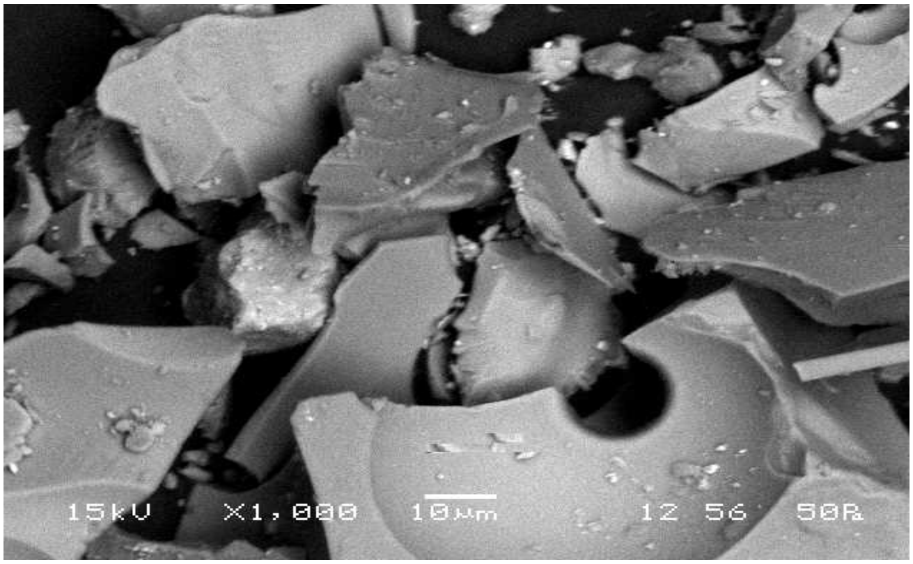

Fig: 3.13 .Microstructure of ground granulated blast furnace slag

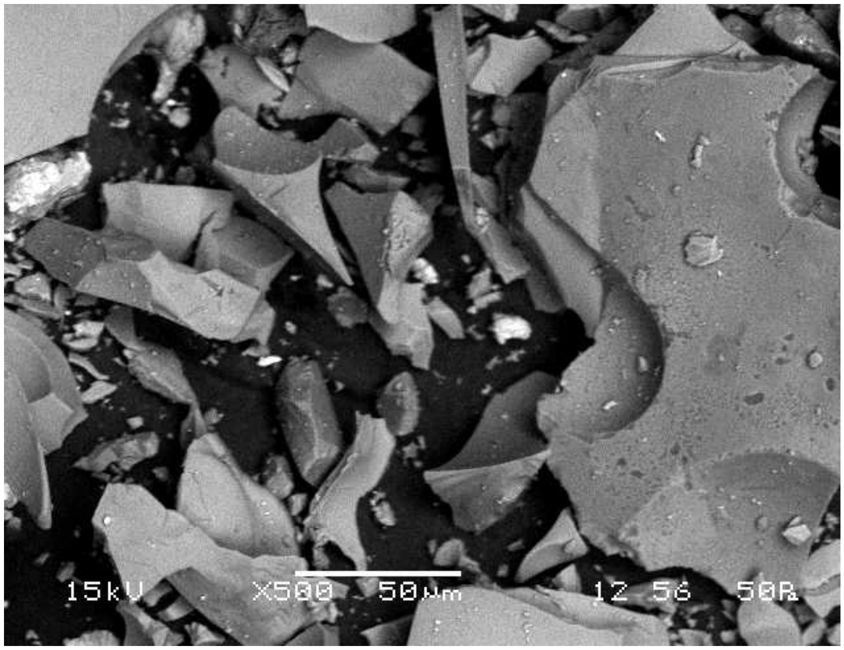

Fig: 3.14 Microstructure of ground granulated blast furnace slag

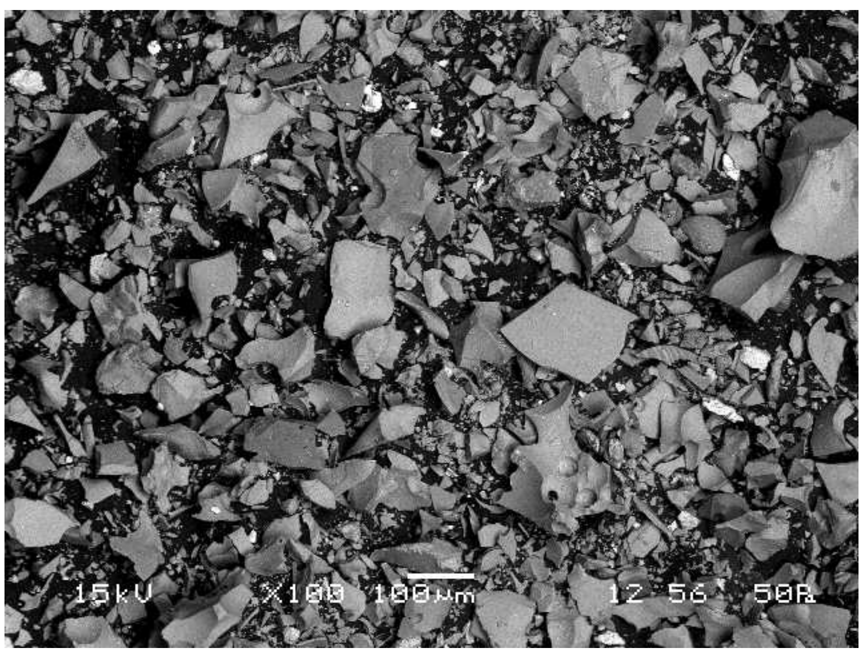

Fig:3.15 Microstructure of Ground granulated blast Furnace slag

Table 3.7Sieve Analysis of Fine Aggregate:

Sieve Size	Weight retained(kg)	%(Retained)	%Cumulative Retained Rn	% Cumulative passing(100-Rn)
4.75	0.070	7.0	7.0	92.2
2.18	0.090	9.0	16.4	83.6
1.2	0.290	29.0	45.0	55
0.006	0.356	35.6	80.6	19.4
0.003	0.156	15.2	95.8	4.2
0.0015	0.036	3.6	99.4	0.6
pan	0.0006	0.6	100	0
Total	0.9986	100		

From the sieve analysis of table the fine aggregate was under the zone-II.

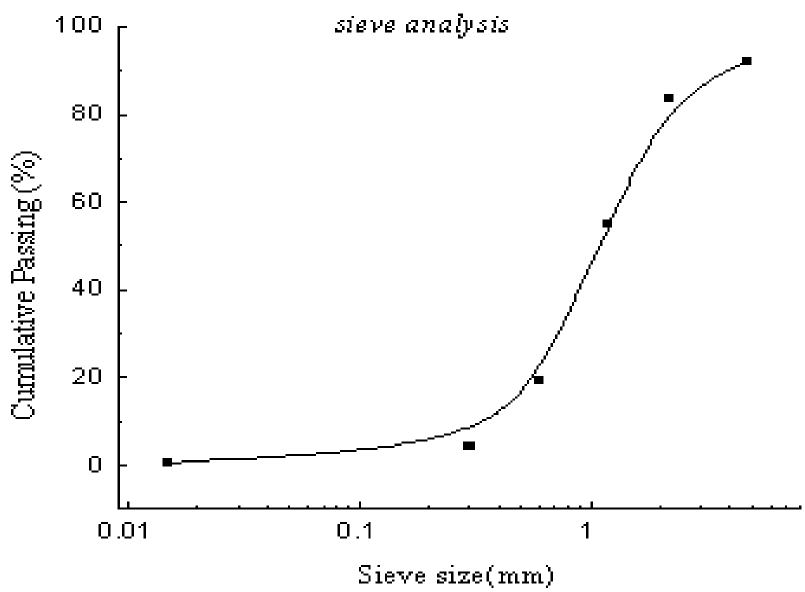

Figure 3.16 Sieve Analysis of Fine Aggregate

It can be seen from table 3.3 that sieve with the maximum amount of fine aggregate related is the sieve size of 600 mm which is 35% of the total weight of the fine aggregate sieved . Figure shows the cumulative passing in percentage versus sieve size which was obtained from the table.

3.24 Lime

Lime was procured from the market. It was air dried and mixed thoroughly in dry condition. It was passed through 150 micron sieve. Then Lime was stored in air tight container for subsequent use. The XRD test result of lime sample is shown in Fig.3.17. From the figure it can be observed that calcium oxide and magnesium oxide are predominantly present

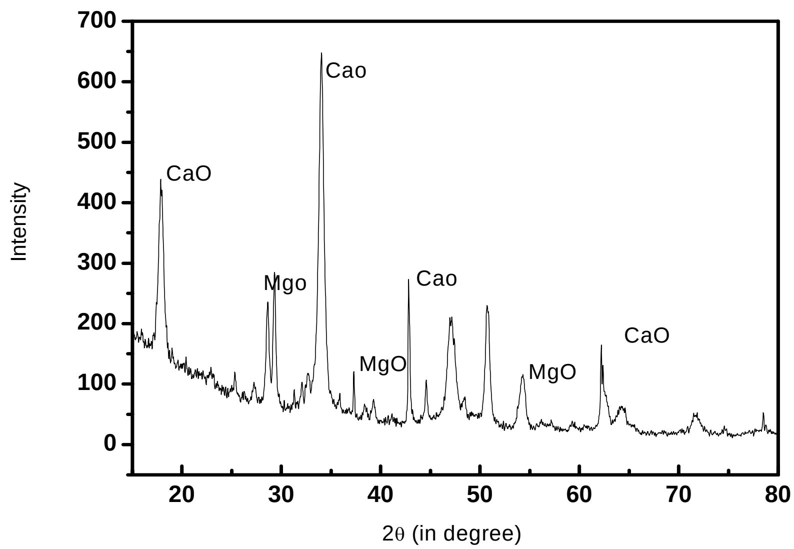

Fig . 3.17. X-ray diffraction of Lime

Table 3.8Chemical Composition of Lime

Composition	Lime Present Study	CPBC
CaO	50	40-48
MgO	30	30-38
H_2O	20	15-17

The microstructure and distribution of lime were studied. Micro-photographs of the sample are shown in fig. (3.17-3.19) and fig .3.20. It is clearly observed that most of the particles are spherical structure with few irregular particles. The surfaces of spherical particles are found to be and smooth as it is a high calcium Lime with particle size varying from 1μm to 25μm.

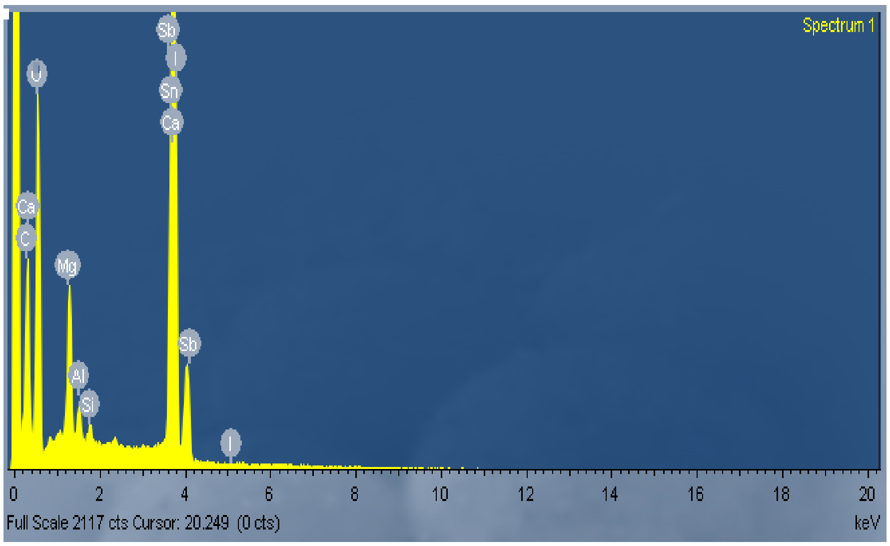

Fig: 3.18.Microscopic pattern of lime

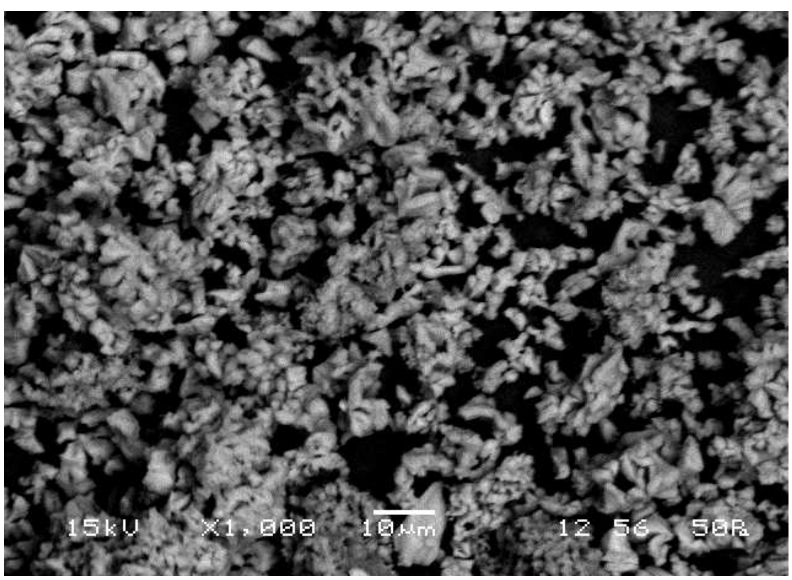

Fig: 3. 19 Microstructure of Lime

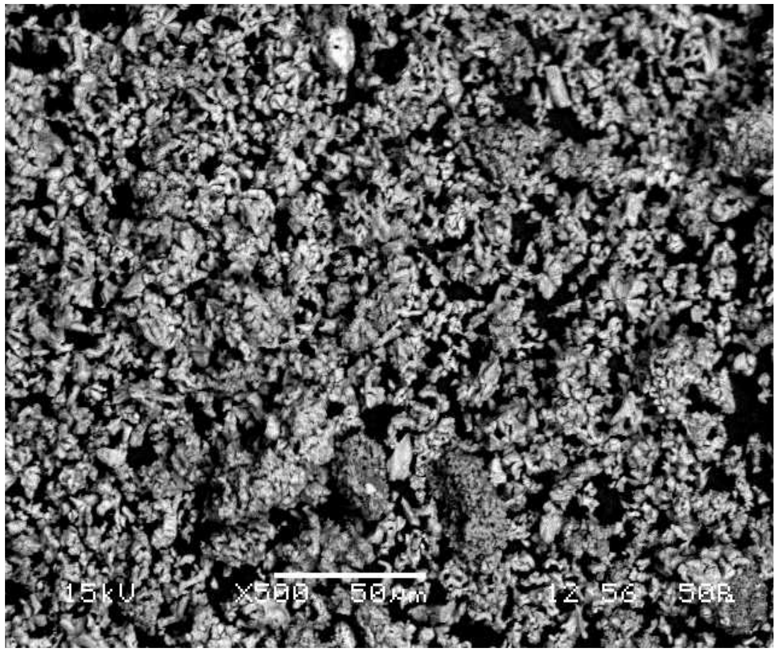

Fig.3.20 Microstructure of Lime

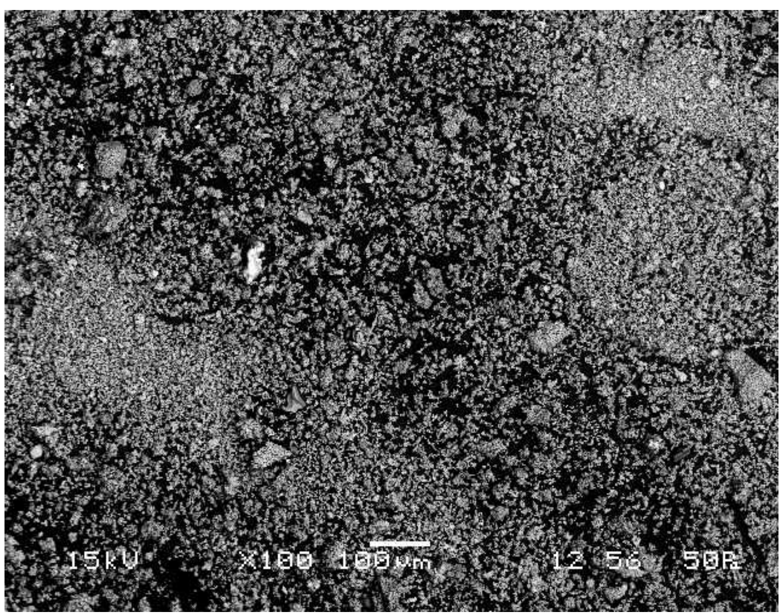

Fig.3.21. Microstructure of Lime

3.3PROPERTIES OF FRESH CONCRETE:

Slump and workability

It generally known that the replacement of Portland cement by fly ash and lime in concrete increase the water requirement is a to obtain a given consistency or water binder ratio. Increases the workability slump for given water content compared to that of concrete without cement.

3.32 MECHANICAL PROPERTIES

Strength development

The strength development of fly ash concrete is strongly affected by the type of fly ash and the curing temperature. The use of low- calcium fly ashes and lime generally decreases the compressive strength of concrete at early ages (up to 28 days) and increases it at later ages (due to pozzolanic reaction of fly ash) when compared to Portland cement with similar 28–day compressive strength. On the other hand, the use of high calcium content has a marginal effect on strength development.

In cool weather, the low temperature generally slows the chemical reaction between cement and water, and thus the strength development of concrete. For fly ash concrete, this effect is more pronounced due to reduced Portland cement in the mixture and greater dependence of pozzolanic reaction on temperature.

3.4 CONCRETE MIXTURE PROPERTIONS:

The procedure for selection of mix proportions used for Portland cement concrete is also applicable to concrete incorporating fly ash, lime or slag with some modifications. The main steps of procedure are as follows

Selection of water-to compendious materials ratio to meet durability and strength parameters.

- Calculation of cement content i.e. Lime + fly ash
- Calculation of coarse aggregate content.
- Calculation of fine aggregate content.
- Adjustment for aggregate moisture, and;
- Trial batch adjustments.

The above steps may be affected depending on the method used for of fly ash lime and GGBS in concrete.

3.5 Simple Replacement method

This method consists of direct replacement portion of Portland cement by fly ash or lime by volume or by mass, which mainly consists of modifying an existing Portland cement mix to include fly ash or GGBFS lime without other adjustments. The concrete designed with this method usually has performance compared to that of concrete made with Portland cement.

Modified replacement method

This method consists of developing fly ash /lime concrete mixtures with similar workability and compressive strength to that of Portland cement concrete at a specified age. In general, this concrete has a higher total weight of cementoius materials and higher water cement ratio.

3.6ESTIMATION OF MIXING WATER

As mentioned earlier, the use of fly ash in concrete generally reduces the water demand required to achieve a certain level of workability , while the use of lime GGBS does not significantly affect the water demand. Therefore each type of fly ash and fly ash content (and the same thing for lime to same extent) data was developed to replace values usually used that provides the approximate mixing water content for different slumps and nominal maximum size of aggregates. Mixing water was also dependent on the GGBFS gradation which was used as sand.

3.7 COMPRESSIVE STRENGTH

The compression test is the most important test that can be used to assured the engineering quality in the application of building materials. The optimum lime content in the mixture of lime and fly ash were determined by conducting the compression test on mortar specimens as per I.S Code of practice 4301 part-7 (1988).Compressive strength of mortar tests were done in all specimens produced at period of 3, 7, 28 and 56days. Total 12 numbers cubes are produced for each water/ lime + fly ash used in the trial mix. From 12 cubes 3 cubes were tested for 3 days and other 3 cubes at7 days and remaining 3cubes at 28 days and 3 cubes at 56days. The values of all specimens tested 3rd 7th 28th and 56days were recorded and average value was calculated. The equipment used for the compressive strength test could produced reading which represents the rate of loading. For the Compressive strength there were two series of test done one is for compressive strength for mortar and other is for concrete. For the mortar test the sample were from fly ash with different lime content keeping ground granulated blast furnace slag as fine aggregate. The ratio of powder and GGBS (Ground granulated blast furnace slag) was taken to be 1:2 and 1:3 and six different types of specimen were prepared by varying the lime content (20, 35,50,65,80 and 100%).

To find out the effect of curing period on compressive strength, the samples were cured with curing period of 3 day, 7 day 28day and 56 day. Similarly, to prepare the SSHM (steel slag hydrated matrix), the mix proportion of powder, GGFBS and steel slag was taken as 1:1.5:3. Here also six different types of specimen were prepared by using different lime and fly ash content.

A specimen of normal concrete with the mix of 1:1.5:3 (cement: sand: aggregate) was prepared to compare with the new SSHM. The w/c ratio was taken to be 0.55. Steel slag concrete cubes were prepared taking lime+fly ash binder, GGBFS and steel slag and lime content in lime, fly ash mix was varied as 20, 35, 50, 65 and 80 percent. To find the effect of curing period on compressive strength, the samples were cured with curing period 7 day and 28 day.

3.8 TENSILE FLEXURAL STRENGTH OF CONCRETE

Flexural test is intended to give the flexural strength of concrete in tension. The testing of concrete to flexural yields more consistent result than those obtained with tension in concrete ; the flexural test also more easily carried out and may have been be more convenient than the test for used in field . It is measured by loading 100 x 100 x 500 mm concrete beam called prism. The flexural strength is expressed as Modulus of rupture and is determined by test method referred in IS 516-1959 by using two points loading method. For testing the specimen is placed in the machine and load is applied and increased continuously at rate of 180 kg/min, until the specimens fails. The maximum load applied to the specimens during the tests are recorded and used to calculate flexural strength of the concrete using the formula.

$$\text{Flexural strength} = M/ Z = Wl/bh^2$$

In this expression W is in Newton and l, b and h are in the millimeters, all strengths are in N/mm^2.

For flexural strength different proportion of lime has taken i.e. (20 %, 35%, 50%, 65%, 80%) with variation of fly ash. It was tested for 7 days and 28 days.

3.9 SPLIT TENSILE STRENGTH

The splitting tests are well known indirect tests for determining the tensile strength of concrete sometimes referred as split tensile strength of concrete. This tests were carried out in accordance with IS 516-1999 standards conducted on concrete cylinders of 150 mm diameter and 300 mm length. Each cylinder specimen was placed on its side and loaded in compression along a diameter of the tested cylinder specimens. The load was continuously applied at a nominal rate within the range of 1.2N/ (mm2/min) to 24N/ (mm2/min) till the specimens failed. The maximum load applied to specimen during the test were recorded and used to calculate split tensile strength of SSHM concrete. The magnitude of tensile stress is given by the formula

$$\sigma_{SP} = \frac{0.675W}{LD}$$

Where

σ_{SP} = Split tensile stress, L= length of cylinder and D= Diameter of Cylinder.

The split tensile strength of the steel slag concrete was tested for 7 days 28 days with lime content 35%, 50 % and 65% which were given the better result in mortar compressive strength.

Fig: 3.22. Cylinder for split tensile strength

CHAPTER 4

RESULT AND DISCUSSION

Chapter4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results obtained from the testing of mortar prepared from hydrated lime, fly ash and GGBFS and strengths of steel slag hydrated matrix are presented. The conventional procedure followed to characterize the quality of cement is adopted in the first phase of tests and best raw material composition was arrived at. In the second phases, concrete specimens were prepared with taking steel slag as coarse aggregate ground granulated blast furnace slag as fine aggregate and binder that is found to best performance from the test of phase one. The composition of above raw materials was varied to study the effect of raw material compositions on compressive strength, flexural strength and tensile strength adopting conventional testing procedure. The effect of curing period on strength was also studied and reported. Comparison is also made between the Steel slag hydrated matrix and the conventional concrete.

4.2SETTING TIME OF LIME+FLY ASH

Setting time

The initial setting and final setting times of various mixes of lime-fly ash is given in Table 4.1.In general it is observed that both the initial and final setting times of fly ash lime mixes are comparably higher than the conventional cement.

Table 4.1 Setting time and consistency Lime+ fly ash

Lime + Fly ash	Water/ Lime + Fly ash		Consistency		Initial Setting Time		Final Setting time	
	Sample1	Sample2	Sample1	Sample2	Sample1	Sample2	Sample1	Sample2
100+0	0.69	0.69	0.58	0.58	1hr30min	2hr17min	23hr30min	25hr02min
80+20	0.67	0.67	0.56	0.56	1hr25min	2hr14min	23hr35min	25hr01min
65+35	0.65	0.65	0.56	0.56	1hr48min	4hr52min	26hr20min	27hr30min
50+50	0.62	06	0.53	0.51	5hr40min	8hr20min	26hr20min	27hr30min
35+65	0.53	0.52	0.45	0.44	5hr10min	5hr20min	24hr10min	10hr47min
20+80	0.5	0.47	043	0.4	2hr35min	5hr29min	5hr25min	11hr01min

4.3 COMPRESSIVE STRENGTH OF MORTAR

The compressive strength of mortar was found to be less strength in earlier stage but it was increase with curing period and which is same as cement mortar. The detail was given in Table4.2 and Table 4.3

Figure 4.1: Loading arrangement for determination of the compressive strength (mortar)

Table: 4.2Variation of Compressive strength of mortar Lime+ Fly ash: GGBS (1:3)

Water/ Lime, Fly ash ratio	3Days	7Days	28 Days	60days
0.50	4.65	7.2	15.4	38.8
0.53	4.43	6.35	13.53	37.86
0.62	4.29	6.28	12.6	34.34
0.65	3.46	6.18	12	31.86
0.68	2.85	5.89	10.37	29.6
0 .69	2.65	5.65	10.12	29.4

Table4.3 Variation of Compressive strength of mortar Lime+ Fly ash: GGBS (1:2)

Water lime + fly ash ratio	3Days	7 Days	28Days	60days
0.50	5.13	17.56	12.6	37.86
0.53	8.87	9.71	13.53	33.36
0.62	7.19	7.33	15.4	30.8
0.65	4.25	12.67	12.78	28.8
0.68	7.84	7.0	10.37	28.2
0.69	6.20	6.5	10.11	28.2

After calculating the compressive strength of each specimen, an average value of compressive strength of 3, 7, 28 and 60 days was calculated with the respective water/ Lime+ fly ash ratio. Results were inserted to graph to analyze the production of strength of each different ratio**.**

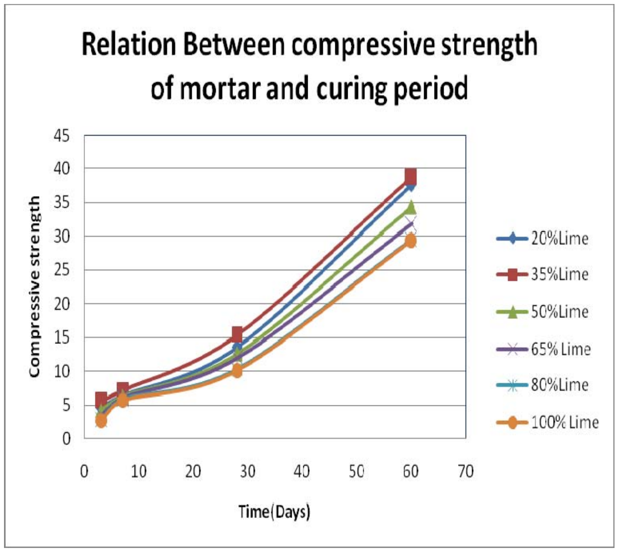

Figure: 4.2Variation of Compressive strength of mortar (1:3)

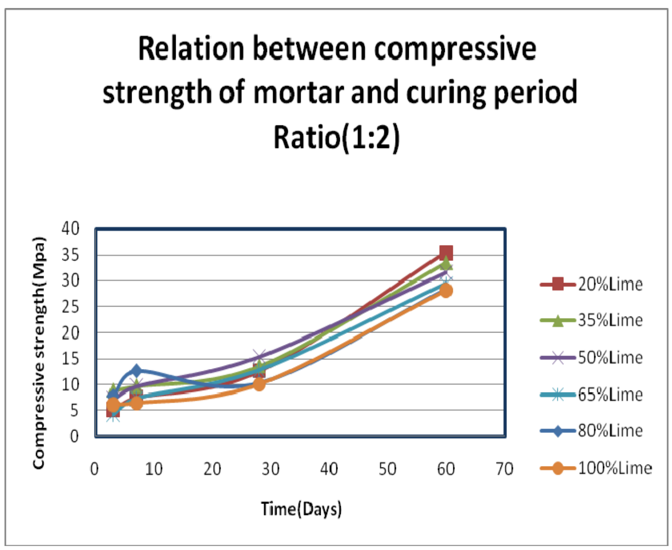

Figure4.3 Variation of Compressive strength of mortar (1:2)

From Fig 4.2 and Fig 4.3 it is concluded that the mortar exhibit low early strength but shows considerable increase in strength with curing period. The low early strength may be due to the slow reaction between the powder (Lime+ fly ash) and the water. But the reaction continues for a longer period and more gain of strength with age. It is little inconclusive in which way it changes with respect to different powder mix (lime+ fly ash). But the mortar with 35% lime content gives the maximum compressive strength among all six proportions.

The compressive strength of mortar with lime content were given below the graph.

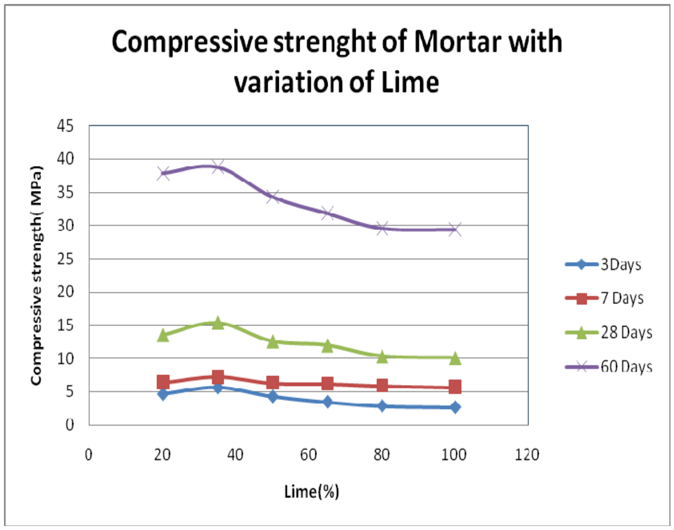

Figure4.4 Variation of Compressive strength of mortar (1:3) with Lime content

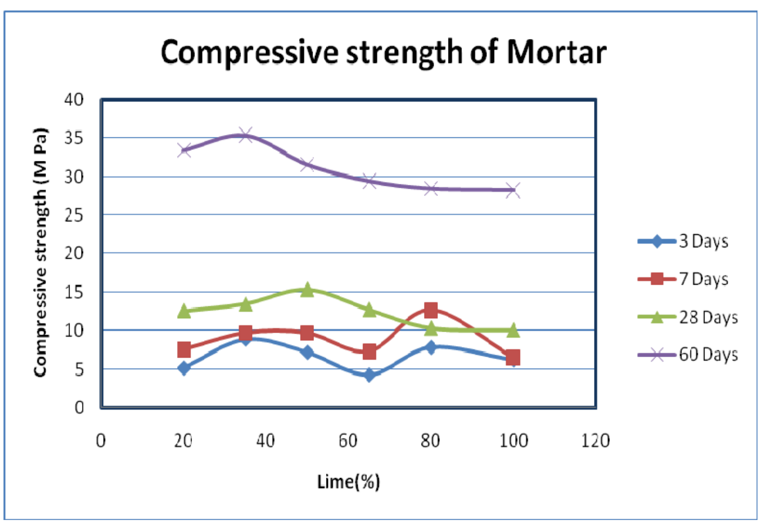

Figure:4.5Variation of Compressive strength of mortar(1:2) with Lime content

Fig (4.4) and Fig (4.5) depicts that the compressive strength of mortar increases with curing period. At, the Fig (4.4) and Fig (4.5) one may observe that it is less strength in earlier stage but after 28 days it becomes same as the cement mortar.

4.4 COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of steel slag aggregate concrete decreased with the proportion of lime content. The compressive strength varied from 12.5MPa, for concrete with 20% lime content10MPa, to 12.5MPa for concrete with 35% lime content. The Steel slag Hydrated Matrix Concrete was compared with Normal concrete and the compressive strength of Normal concrete was 24.2MPa. The compressive strength of steel slag aggregate concrete is less than the normal concrete. The steel slag was full of impurities particles like coal, burnt soil lumps and some other materials and also presences of excess lime .These have swelled after coming in contact with water and consequently creating cracks in the Steel slag hydrated matrix. The crack pattern in the cube was shown below the Figure-4.6. Therefore, the compressive strength of concrete was less than the normal concrete.

Figure 4.6 crack pattern in Cube

Further for steel slag hydrated matrix and normal concrete compressive strength at 7 days and 28 days were calculated given in table4.6 and 4.7 respectively. The comparison between compressive strength of steel slag hydrated matrix and normal concrete is in Fig (4.8).

Figure: 4.7 loading arrangement for determination of the compressive strength.

Table: 4. 4Compressive strength of steel slag hydrated matrix

Mixture No	Maximum Diameter of steel making slag(mm)	Slump (mm)	Unit content(Kg/m3)					Compressive strength (N/mm$^{2)}$	
			Water	BFS	Lime	Fly ash	Steelmaking Slag	7Days	28Days
A	20	42	256	716	98.4	393.6	1506	6	11
B	20	45	269	716	172	320	1506	6.5	13
C	20	53	285	716	246	246	1506	5	10
D	20	55	306	716	320	172	1506	4.67	9.2
E	20	48	314	716	393.6	98.4	1506	4	9

Table: 4.5 Compressive strength of Normal concrete

Maximum Diameter of aggregate(mm)	W/C (%)	s/a(%)	Slump (mm)	Unit Content (kg/m3)					Compressive strength at 28 days (N/mm$^{2)}$
				W	C	S	G	AD	
20	0.55	-	15	270	492	716	1506		24.44

The above table is the compressive strength of normal concrete at 28 days which is greater than steel slag hydrated matrix.

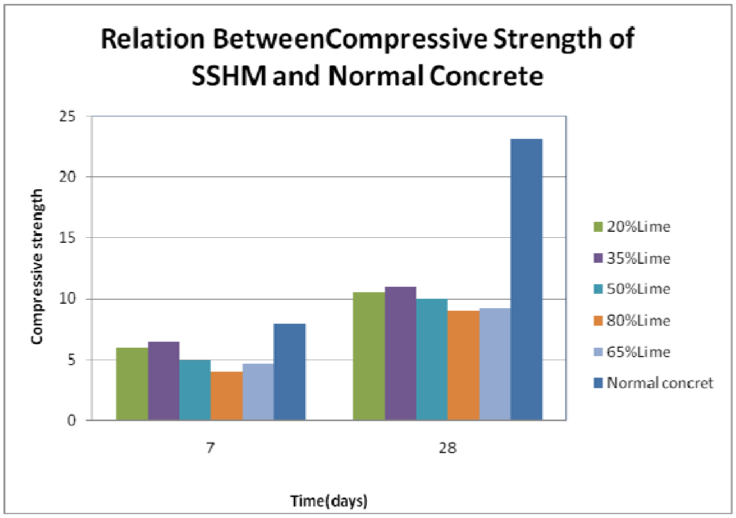

Figure : 4. 8 Comparison of Compressive strength of Steel Slag Hydrated Matrix with Normal Concrete.

Fig (4.8) shows the strength of SSHM is less than the normal concrete. One may observe at Fig (4.8) that SSHM is not equal with the strength shown by the GGBS mortar. It shows there might be some fault with the steel slag. At low early strength the reaction between the powder and water is slow. The reaction continues for longer period which results to considerable gain of strength after 28 days as compared to normal concrete. The Fig (4.2) and Fig (4.3) does not clear which way the proportion of lime and fly ash affect the strength. But the matrix with 35% lime gives the highest strength.

4.5FLEXURAL STRENGTH:

It is increased with proportion of decrease of lime content varying from 2.5 MPa, in the 35% lime content of concrete is the higher Flexural strength of 2.5 MPa .slag aggregate concrete. The flexural strength of Normal concrete was 4.3 MPa. These results indicate that the improvement in the flexural strength, due to the impurities of steel slag aggregate.

Table : 4.6 Flexural Strength of Steel Slag Hydrated Matrix with Normal concrete

Steel slag Hydrated matrix			Normal concrete at 28Days in (MPa)
Flexural strength in MPa			
% Lime +Fly ash	7 Days	28 Days	
0.5	0.50	2.0	4.3
0.53	0.65	2.5	
0.62	0.45	1.8	
0.65	0.35	1.46	

Figure: 4.9 loading arrangement for determination of the flexural tensile strength.

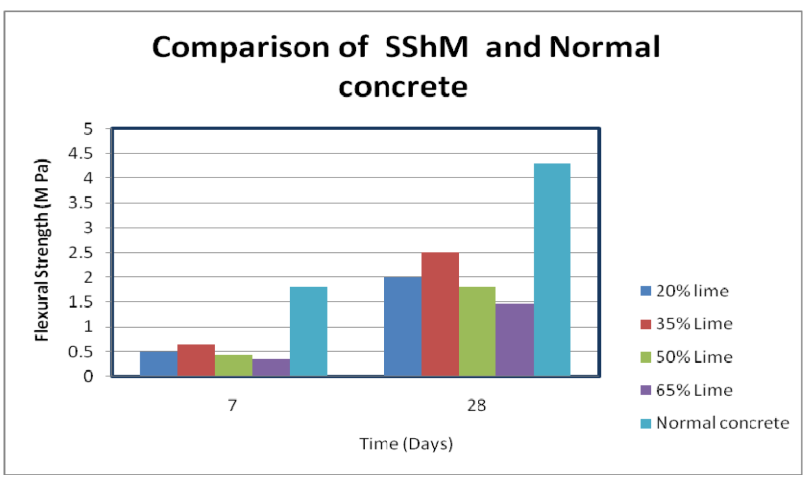

Figure: 4.10 Comparison of flexural Strength of Steel Slag Hydrated Matrix with Normal concrete

From the Table (4.8) and Graph (4.10) it shows that flexural strength of Steel slag hydrated matrix is less than the normal concrete. In generally the flexural strength of Steel slag Hydrated Matrix was less than the Normal Concrete from chapter -2 (Literature Review) also.

4.6SPLIT TENSILE STRENGTH:

The split tensile strength of the Normal concrete was 2.22 MPa while it was in the range of 2.1 to 2.13MPa in the steel slag aggregate concretes. The split tensile strength of the steel slag aggregate concrete was less than that of Normal concrete. But it was same as the Literature.

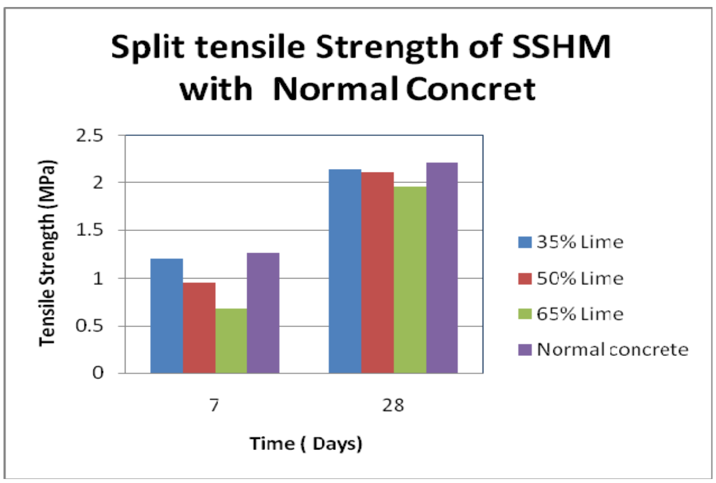

Figure: 4.11 Comparison of Tensile strength of Steel Slag Hydrated Matrix with Normal Concrete.

From the Fig (4.11) it shows split tensile strength of Steel slag hydrated matrix with proportion 35% lime content is nearly same as Normal concrete.

REASON FOR LOWER STRENGTH

Some other researchers have found the compressive strength of SSHM in the range of 20 N/mm^2 to 30 N/mm^2 after 28 days of curing. But in our case we have got compressive strength in the range of $9N/mm^2$ to $13N/mm^2$. This lower strength of SSHM may be due to the following reasons:

- The steel slag was full of foreign particles like coal, burnt soil lumps and some other materials and excess of lime. These have swelled after coming in contact with water and consequently creating cracks in the SSHM.
- There were too much dust particles in the steel slag covering the surface of it hence opposing the cohesion and interlocking between the slags and subsequently resulting in low strength.
- There were foreign particles in the GGBFS. Moreover it was not stored in a confined container rather was exposed to the atmosphere hence decreasing the activity of GGBS.
- The slaked lime was impure with less CaO content.
- Though the maximum size of steel slag was 20 mm it was a poorly graded one.
- Use of high water powder ratio which could have been reduced using some admixtures like super plasticizer.

CHAPTER 5

CONCLUSION & SCOPE FOR FUTURE WORK

Chapter-5

CONCLUSION

From the present studies following conclusions were drawn-

- The compressive strength of mortar that is lime: fly ash: GGBFS in the proportion of (35:65:300) was found to be 15.6 N/mm^2 at 28 days, 38.8N/mm^2 at 56 days.
- The mortar proportion (35:65:200) it was found to be 13.53 N/mm^2 at 28 days, 35.4 N/mm^2 at 56 days.
- Initial setting time, final setting time and consistency of fly ash and lime powder (binder) is approximately 30% , 25% and 46% more than the cement.
- The compressive strength of mortar Steel slag hydrated matrix was less during earlier stages of curing, but it has achieved almost same strength as normal cement mortar after 56 days.
- The 28 days compressive strength of concrete of Steel slag hydrated matrix is found to be less than the normal cement concrete.
- The compressive strength of SSHM after 28 days of curing was found to vary from 9N/mm^2 to 13N/mm^2. However, other researchers have found the compressive strength of SSHM in the range of 20 N/mm^2 to 30 N/mm^2 after 28 days of curing.
- Flexural strength after 28days of Steel slag hydrated matrix is lower than normal concrete.

- Split Tensile strength after 28 days of Steel Slag hydrated Matrix is approximately same as the normal concrete.
- The material which is used as coarse aggregate, steel slag procured from RSP contains lot of unborn carbon particle in addition to that over burnt lay lumps which could not be separated during sample preparation .During curing of specimen is found that hair cracks starts from the burnt at that clay lumps. This might have reduce the compressive strength, flexural strength of steel slag hydrated matrix.
- Steel slag hydrated matrix has the features like made from 100% recycled resources, same strength performance as ordinary concrete, excellent wear resistance, low alkaline dissolution, and excellent growth habitat for befouling organisms in marine environments. In this project work, all attempts have been made to get an alternative material to concrete using mostly waste products of steel industry. It involves no burning of fossil fuels, which is otherwise used for manufacturing of cement, helps in emission of CO_2 and protects environmental pollution

SCOPE FOR FUTURE WORK

SCOPE FOR FURTHER STUDIES:

The research work on steel slag hydrated matrix is still limited. But it promises a great scope for future studies. Following aspects related to strength characteristics of Steel slag hydrated matrix need further study & investigation.

- To get a rational mix proportion of steel slag, GGBS and powder to get required strength.
- The effect of admixture like superplastizer on SSHM.
- The chemical effect of SSHM on steel reinforcement.
- The long term gain of strength of SSHM may be investigated.

Research work may be done to see the durability aspect of steel slag hydrated matrix.

CHAPTER 6

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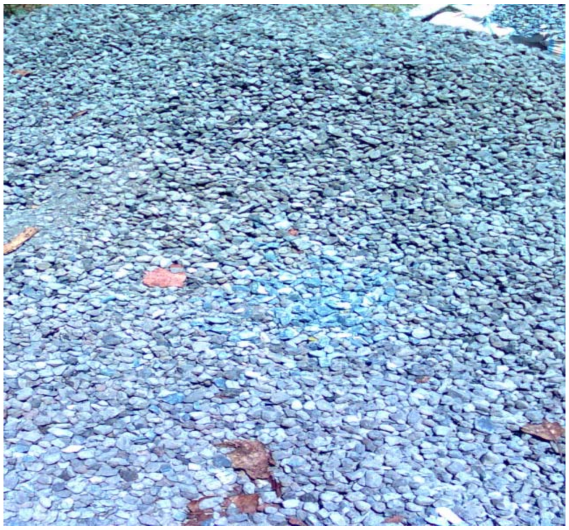
APPENDIX



Steel slag

Ground granulated blast furnace slg

SLUMP TEST OF CONCRET

INSTRUMENT FOR COMPRESSIVE STRENGTH

Compressive strength of Mortar

Samples with Water / Lime+ fly ash ratio 0.5at 3 days

Sample No	Weight (kg)	Loading(KN)	Compressive Strength (MPa)
1	657	27.65	5.38
2	644	26.8	5.36
3	648	26.6	5.35
		Average	5.31

Sample No	Weight (Kg)	Load(KN)	Compressive strength(MPa)
4	658	44.35	8.87
5	652	4.3	8.56
6	672	44	8.81
		Average	8.87

Samples with Water / Lime+ fly ash ratio 0.53at 3 days

Samples with Water / Lime+ fly ash ratio 0.653at 3 days

Samples No	Weight(Kg)	Load(KN)	Compressive strength (MPa)
7	658	37.5	7.5
8	652	34	6.8
9	672	36	7.2
		Average	7.19

Samples with water/ Lime +fly ash ratio 0.65 at 3 days

Sample No	Weight (kg)	Load(KN)	Compressive strength (M Pa)
10	672	24.5	4.9
11	658	23.8	4.76
12	668	24.5	4.9
		Average	4.25

Samples with water/ Lime +Fly ash ratio 0.68 at 3 days

Samples No	Weight (Kg)	Load (KN)	Compressive strength (M Pa)
13	672	42	8.4
14	658	34	6.8
15	666	37.5	7.5
		Average	7.84

Samples with water/ lime + fly ash ratio 0.69 at 3 days

Samples No	Weight(Kg)	Load(KN)	Compressive strength (M Pa)
16	674	31.5	6.3
17	658	29	5.8
18	670	32	6.4
		Average	6.2